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NAVY ENVIRONMENTAL SUPPORT OFFICE PORT HUENEME CA
ASPECTS OF INDUSTRIAL WATER TREATMENT.(U)

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FOREWORD

Water used in industrial processes is chemically treated to reduce equipment corrosion, to inhibit algae growth, or to assure quality control of manufactured products. In the instances of corrosion and algae control water treatment frequently assists process operators to maintain higher equipment efficiency and yield a commensurate reduction in energy consumption.

The concepts of energy conservation and maintenance minimization are beneficial results of water treatment. However, because industrially-used water does not usually operate in a closed system, it must be discharged to the environment. At this point several potential problems must be faced due to increased regulatory control by environmental agencies. Specifically, discharges must be characterized in terms of kind and quantity of chemicals contained.

This publication summarizes information about various aspects of water treatment for industrial use. Most operational phases of treatment are discussed, including water quality and industrial requirements; water supplies and sources of impurities; water treatment methods and chemicals used for treatment; and, environmental aspects of water treatment. The report also provides reference material useful for planning, designing, operating, and evaluating water treatment facilities. Revisions to this report will be issued as appropriate and recipients are invited to submit recommended changes.

JOHN A. LUCAS, JR., LCDR, CEC, USN
Director
Navy Environmental Support Office

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I. INTRODUCTION

A. SCOPE OF PROBLEM

Water from groundwater and surface water supplies in many cases must be treated before it can be used for a number of industrial processes, including boiler water, cooling water, etc. The quality of potable water for 97 of the 100 largest cities in the United States is indicated by purity of over 99.95% based on the dissolved solids content. However, the 0.05% impurity in water is sufficient to cause a variety of problems if the quality of water is not controlled before and during industrial use.

Two considerations other than the process requirements dominate industrial water treatment: environment and energy. The following trends stem from these considerations: In boilers it has been and is becoming more important to wring out the last Btu from every gallon of fuel; this requires minimum scaling, corrosion, and blowdown; highly effective chromate-phosphate-zinc corrosion inhibitors for cooling water are being replaced by using treatment methods that have smaller environmental impact; biocides may have to be replaced by others that are readily detoxified. The overall goal in all of these trends is to improve the quality of the water and, at the same time, reduce the consequences of releasing residues from water treatment to the environment.

Although today's research and development is larger and more costly than previously, it is producing new treatment methods that are as effective as those banned for environmental considerations.¹ These new methods sometimes require closer attention to process controls and also additional emphasis on quality control to avoid more serious problems. Better trained personnel and more detailed procedural manuals will also be required.

B. PURPOSE OF REPORT

This report reviews and summarizes industrial water treatment practices. Current and projected chemical and analytical procedures are identified. A thorough understanding and monitoring of water treatment operations should provide the necessary data to allow resources to be conserved and to lower the cost of pollution abatement. This can be accomplished by working toward eliminating the sources of pollution in processes and products before waste is created. The goal is to apply knowledge based on the data to provide the most rational use of natural resources and energy and to protect the environment.

This report completes the first phase of an effort to review and, as necessary, implement a data collection program in the water treatment area so that the above objectives can be met. The complete effort involves the review and summary of current water treatment practices (this report), the current status and future trends at naval facilities, the development of a program of data collection and use, engineering and laboratory support, and an implementation plan for supporting energy conservation and environmental programs.

II. WATER QUALITY AND PROCESS REQUIREMENTS

A. WATER QUALITY PARAMETERS

1. Water quality is characterized by the kinds and concentrations of impurities in water. These impurities are determined by quantitative tests and sometimes by subjective tests such as taste, odor, and appearance. Normally, a number of parameters or constituents are important for each intended use of water, and the emphasis or order of importance of the constituents varies depending upon the use for which the water is intended. For example, drinking water quality will emphasize toxic and then esthetic constituents; whereas water quality criteria for boiler use and for cooling emphasizes constituents that cause corrosion and scaling, and quality criteria of wastewaters emphasize constituents peculiar to the process generating the waste as well as the level of various constituents permissible to the environment.

2. Lists of common constituents found as impurities in water vary depending on the background involved in developing the list. The list in Table 1 contains constituents based primarily on test procedures for the analysis of pollutants in wastewater for environmental protection purposes. Other lists are not quite as long but include some parameters not listed in Table 1. Drinking water parameters, in addition to many of those listed in Table 1, frequently include:

- Noncarbonate hardness as CaCO_3
- Odor
- Taste
- Trace organic defined by carbon chloroform extract (CCE)

Boiler-feedwater and boiler water tests also include:

- Causticity
- Tannin

3. Numerous additional parameters could be added, including many compounds of commercial importance, bacteria and viruses, and various metabolic and degradation compounds. Many of these additional parameters are determined routinely where circumstances dictate.

4. Water quality data are more meaningful where information concerning the sample to provide the data are well documented. The information about the sample includes sampling site location, time and date of collection, gage height, sampling procedure and equipment, information pertaining to the sampling including climatological data, and names of individuals collecting and analyzing samples.

B. CONCENTRATION UNITS

1. The concentrations of various constituents are reported or expressed in several ways. The choice of a particular unit depends on how the data is to be used or on the traditional way in which particular data is presented. Units used in reporting concentration include weight per unit volume (milligrams per liter), weight per unit weight or volume per unit volume (parts per million or parts per thousand), equivalent weights or moles per unit volume or weight, percent volume, equivalent weight as another constituent or compound, and other units.

2. A common unit for describing water quality, in which concentration is reported is: 1 part per million (ppm) = 1 milligram per liter. The U.S. Geological Survey² has arbitrarily selected 7,000 ppm as the concentration of dissolved solids above which a density correction must be made. Above 7,000 ppm, the determined concentration of each constituent, in milligrams per liter, must be divided by the density to give the correct parts per million value to three significant figures on a weight basis.

3. To obtain approximate data on the amount of dissolved solids in most natural waters, the specific conductance, in micromhos, multiplied by 0.65 approximates the residue on evaporation in parts per million. The factor may be considerably less than 0.65 for waters containing appreciable concentrations of free acid, caustic alkalinity, or sodium chloride. As saturation is approached, the relationship becomes indefinite for most waters. On occasion, it is necessary to determine the equivalents per million of cations or anions in water. With limitations similar to those mentioned above, the specific conductance divided by 100 approximates the equivalents per million of cations or anions.

4. Several tabulations of constants and conversion factors are available to allow convenient conversion from one unit of concentration to another. These lists are particularly useful to an engineer responsible for decisions concerning water treatment processes. Some of the more commonly used factors are included in Tables 2 through 4. Table 2 lists the formula weights and equivalent weights of the most common ions found in water. Table 3 lists factors for converting parts per million to equivalents per million. Table 4 lists several factors for converting from one concentration unit to another and for changing concentrations of one species into an equivalent weight of another species or compound. Table 2 provides the values which can be used to obtain either millimoles or milliequivalents per liter by dividing the ppm value by the formula or equivalent weight, respectively. In water treatment calculations, it is often convenient to express other metals and compounds in equivalent concentration of calcium carbonate (CaCO_3); Table 4 contains factors for this and other conversions.

C. QUALITY OF WATER SUPPLIES AND SOURCES

1. Water quality is determined by the amount of the various constituents dissolved or suspended in water. Most of the potable water comes from surface or groundwater sources, and the quality inputs to these sources which lead to water impurities are summarized in Tables 5, 6, and 7.

2. Waters are classified³ according to their dissolved solids content as follows:

<u>Class Name</u>	<u>Total Dissolved Solids (Parts per Million)</u>
fresh	0-1000
brackish	1000-10,000
salty	10,000-100,000
brine	more than 100,000

or by hardness:

<u>Class Name</u>	<u>Hardness as CaCO₃ (Parts per Million)</u>
soft	0-60
moderately hard	61-120
hard	121-180
very hard	more than 180

3. Usually, for most situations where water can be economically treated, the water in question is classified as fresh. The constituents commonly contained in fresh water are found in concentrations ranging from less than a part per billion for the trace constituents, up to 1000 parts per million or more for major constituents. The constituents commonly found and classified as to relative abundance in water supplies of 100 of the largest cities in the United States are graphically presented in Figures 1 and 2.

D. EFFECTS OF CONSTITUENTS ON WATER USEABILITY

1. Untreated feedwater can cause numerous problems in boiler operations and other processes. Such problems stem from scale formation, corrosion, foaming, embrittlement of structural materials, and other effects caused by various constituents in water. Table 8 lists effects of common constituents of water.

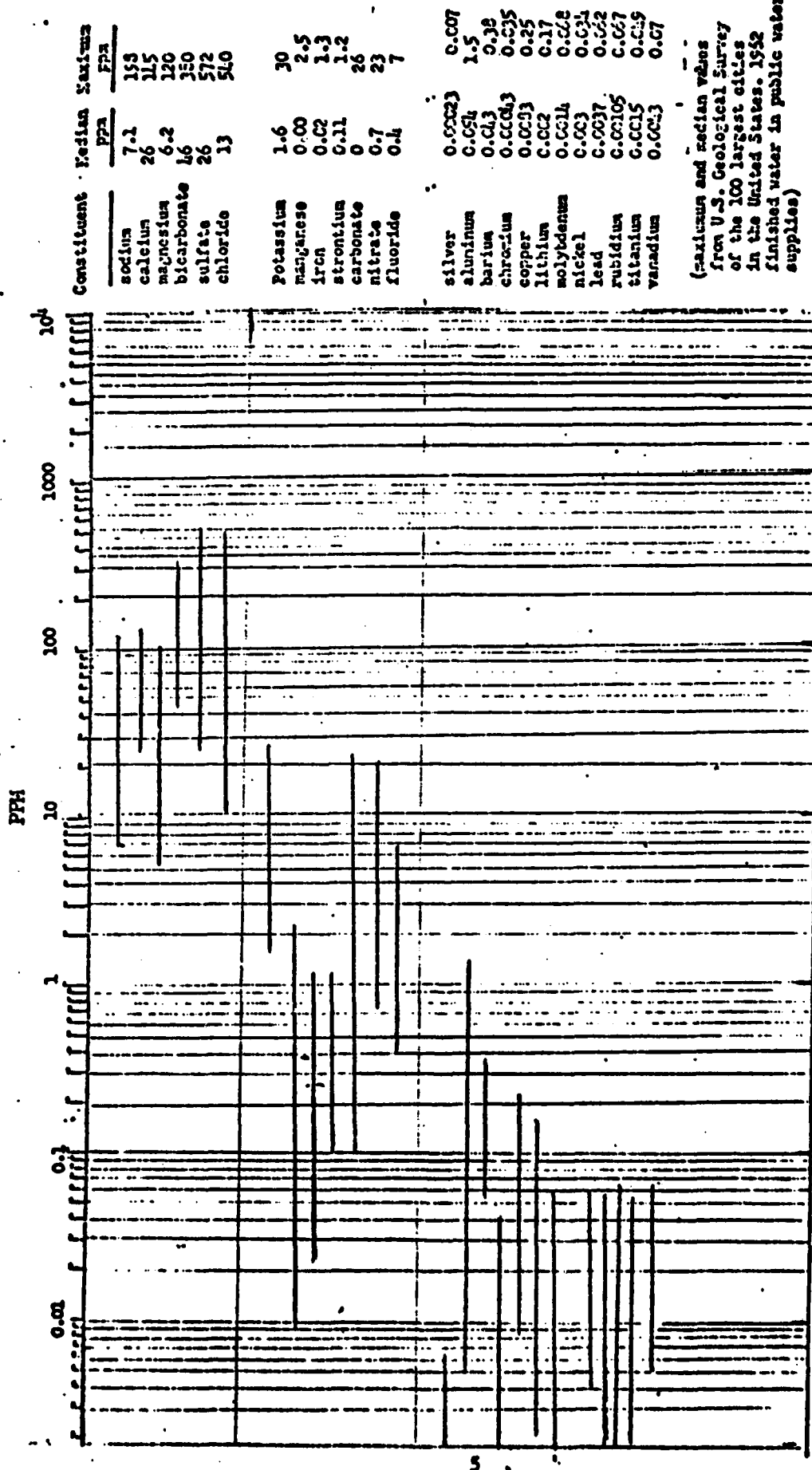


Figure 1. Concentrations of Commonly found Constituents in Water Supplies

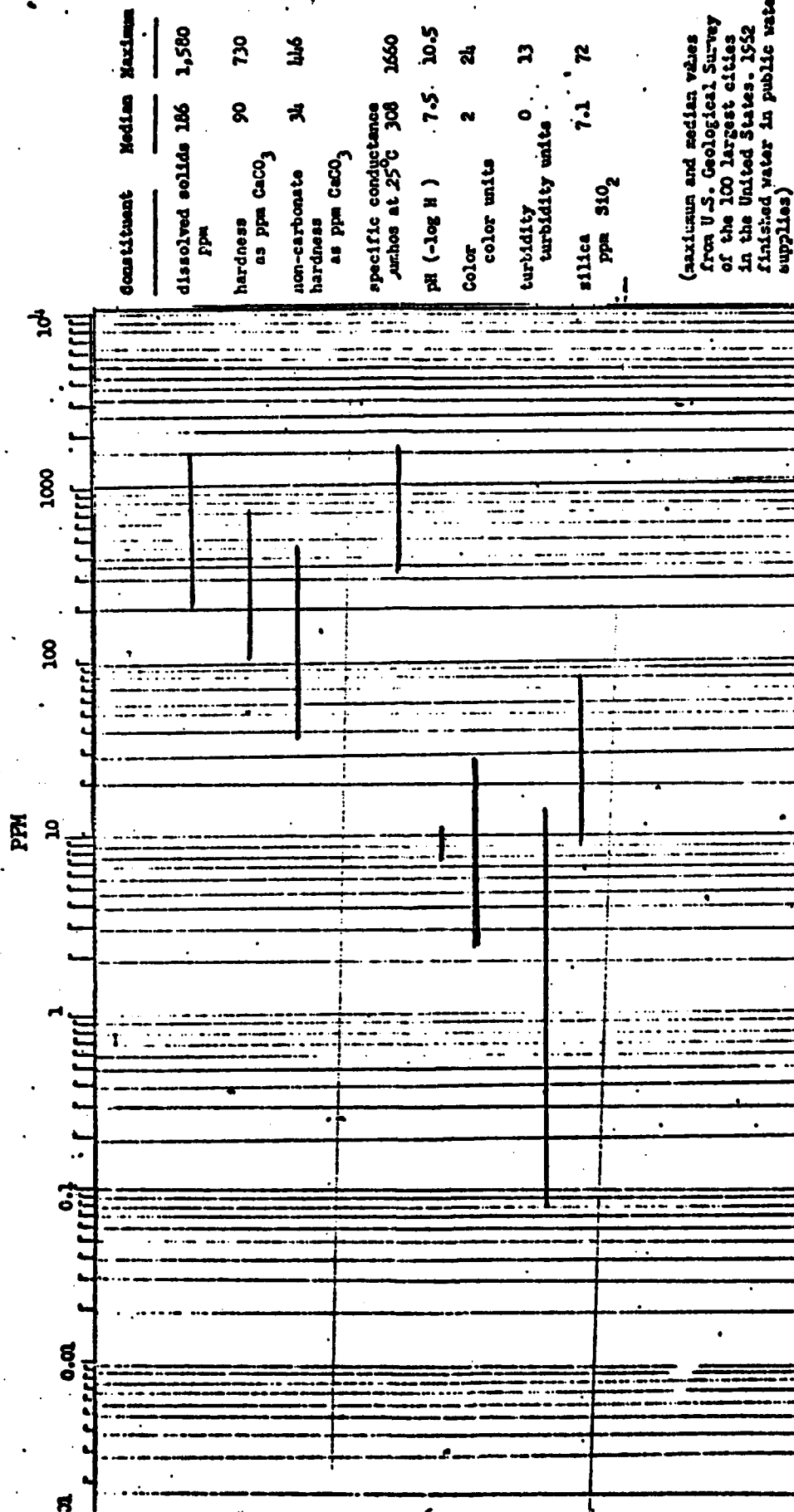


Figure 2. Concentrations of Commonly Found Constituents in Water Supplies

E. RECOMMENDED LIMITS FOR VARIOUS INDUSTRIAL USES OF WATER

1. Water quality requirements and limits vary with the types of industrial processes involved. Recommended limiting concentrations for various industrial processes are listed in Table 9.

2. For boiler feedwater, recommended limiting concentrations for various water quality parameters vary depending upon temperature and pressure of the boiler. Requirements shown in Table 10 list some of the parameter limits which are important in boiler operation.

3. Cooling Water. Water quality requirements vary depending upon whether the system is (1) a once-through cooling water system or (2) a circulating system.

a. Once-through cooling water should have low suspended matter, turbidity less than 50 NTU, iron or manganese below 0.5 ppm, and sulfides below 5 ppm as H_2S .

b. For open circulating systems, the above limits for turbidity, iron and manganese, and hydrogen sulfide apply. In addition, calcium hardness and alkalinity of the makeup should be low enough so that a cooling tower can operate with a circulating water of several concentrations of makeup before scale forms at a significant rate. Additional quality requirements for makeup are less important than some requirements on the quality of the water circulating through the tower. The circulating water must be kept noncorrosive, non-scale-forming, and free from slime and algae growths. In this regard, the features of the construction and operating details of the system are apt to determine the specific concentration limits for particular constituents. Some generalizations concerning the quality of circulating cooling water are shown in Table 11.

c. Closed circulating cooling systems frequently have corrosion problems but not serious scale problems. For corrosion control, it is desirable to have a minimum of 200 ppm sodium chromate with pH maintained in the 7.0 to 8.5 range. Some systems, such as diesel jackets, often carry a minimum of 2,000 ppm sodium chromate to combat cavitation and high temperature effects.

4. Heating Water. Although considered to be closed systems, experience has shown that most closed systems have losses that vary from 10 system volumes per month to almost none, with an average of one system volume per month. Corrosion, the major operating problem, can be minimized by maintaining 500 ppm sodium chromate if treatment control is good, but 2000 ppm is usually recommended. Other corrosion control techniques are borate buffered sodium nitrate at 2,500 ppm or sodium sulfite at a minimum of 50 to 100 ppm. For heating systems at higher operating pressures to 250 psi, the makeup water has to be completely softened and deaerated with pH control at 9.5, a sodium sulfite residual of 50-100 ppm, and a phosphate residual of 30-60 ppm.

5. Other Processes. Additional processes requiring feedwater treatment are photographic processing, where organics and color producing materials need to be removed; and desalinization, which requires alkalinity control and degasification for scale and corrosion control.

F. PROCEDURES FOR TESTING WATER QUALITY

1. Water can carry many substances either in the dissolved or suspended form. For many substances, tests have been devised which can identify and measure the amount of these substances present, provided the concentration is large enough to be detected. A number of references that describe testing procedures and the significance of the test results are identified in paragraph 3 below.

2. A number of analytical methods are usually available for each analysis. The task of the practicing analyst is to choose the analytical method that furnishes the necessary information for a given purpose, with the required rapidity and reliability at a minimum of time and material costs. However, the freedom of choice is frequently limited by regulations. Water analysis in the United States often is guided by APHA, ASTM, and EPA standards. Such methods are generally accepted in analytical practice and are usually applicable to a large number of analysts. Agencies and associations often avoid instrument methods which, although rapid and informative, demand considerable investments and specially trained operators. Because of the large number of possible pollutants, new developments, and the fact that waste materials present many pitfalls, the analyst must have a wide knowledge of methods and should be given broad freedom of choice for selecting an analytical method for a given sample.

3. Procedures for conducting tests for water quality are described in the following references, which are listed under the process or requirement generating the need.

a. General References

(1) Standard Methods for the Examination of Water and Waste Water, 14th edition, 1976. American Public Health Association, 1015 18th Street, N.W., Washington, DC 20036.

(2) Annual Book of Standards, Part 31, Water, 1975. The American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

(3) Methods for Chemical Analysis of Water and Waste, 1974. U.S. Environmental Protection Agency, Office of Technology Transfer, Industrial Environmental Research Laboratory, Cincinnati, OH 45268.

b. Boiler Water

(1) See general list.

(2) Basic Boiler Feedwater Manual, NTTC Course 116, prepared by NAVFAC Technical Training Center, Navy Public Works Center, Norfolk, VA 23511. Department of the Navy, Naval Facilities Engineering Command, Washington DC 20390.

(3) For other details of procedures, see instructions that are usually furnished with test kits, which are available from a number of water analyses equipment suppliers and from the Bureau of Mines, Boiler Water Service, College Park, MD.

c. Wastewater Treatment Plant Tests

(1) See general list.

(2) Laboratory Procedures for Operations of Water Pollution Control Plants, California Water Pollution Control Association Operator's Laboratory Manual, October 12, 1970. Prepared by Joe Nagano, Laboratory Director, Hyperion Treatment Plant, Los Angeles, CA.

III. WATER TREATMENT METHODS

A. DESCRIPTION OF TREATMENT METHODS

1. Water treatment processes commonly used for treatment of raw water for municipal supplies are listed in Table 12. The type of treatment process is listed along with the principal change in water quality factors as a result of the treatment.

Other common but small-scale water treatment methods for special industrial uses include distillation and freezing. The product water from distillation is commonly used in laboratories, and it may be contaminated with ammonia and volatile organics depending upon the air quality around the distillation setup.

2. Chemical Reactions Related to Water Treatment. Most of the water treatment methods described above involve chemical reactions between constituents in the water or between constituents and chemicals added to or contacting the water. These chemical reactions involved in the various treatment methods are summarized in Table 13; the chemicals added are identified by an underline in each equation.

B. CHEMICALS USED IN WATER TREATMENT

1. The chemicals used in the treatment of water and the correction or prevention of problems caused by water quality are listed in Table 14. Some of the chemicals listed may also be used in wastewater treatment. Additional chemicals used in altering and controlling water quality for various uses are listed in the following tables:

Table 15: Chemicals used for Heating Boiler Treatment

Table 16: Chemicals used in Cleaning Steam Generator Systems

Table 17: Chemicals used for Microbiological and Wood Deterioration Control in Cooling Tower Water.

2. The function of the various chemicals are described as follows³:

Phosphates - Various sodium phosphates serve to precipitate the hardness ions, magnesium and calcium, as insoluble lime and magnesium phosphates. Polyphosphates are a form of phosphate that sequester rather than precipitate.

Caustic Soda - Sodium hydroxide is used to ensure proper pH and complete precipitation of the magnesium salts. The optimum pH is 11.0 with a permissible minimum of 7.0.

Chromates and Sulphites - Sodium chromate and sodium sulphite are used to control corrosion. A buffered solution at a pH of 7 to 11 with at least 1,000 ppm sodium chromate is considered optimum. Sodium sulphite is an oxygen scavenger, which reacts with oxygen and is converted from sulphite to sulphate.

Borates - Sodium borates are occasionally used as buffering agents.

Nitrates and Nitrites - Nitrate is used to prevent metal embrittlement. Nitrite acts similarly to sulphites, but under certain conditions where dissimilar metals are immersed in boiler water, particularly copper or brass and soft solder, nitrites can cause very severe localized corrosion unless suitable inhibiting agents are present. Nitrites have not been commonly used for boiler water. Their use is generally confined to hot water systems.

Organic Agents - The organic agents act as protective colloids and tend to keep the insoluble matter in suspension as a sludge and prevent the formation of dense adherent scale on the heat transfer boiler surfaces.

Boiler Compounds - Commercial boiler compounds are for the most part mixtures of the chemicals described above. While the combinations are many, there are two widely used basic types based on: (1) chromates or (2) alkaline salt combinations plus sodium sulphite.

Neutralising Amines - Neutralizing amines neutralize the acid released by the dissolution of carbon dioxide in condensate. They are added to maintain preferred condensate pH values of 8.5 to 9.0.

Filming Amines - Filming amines function by forming a monolayer barrier between the condensate system metal and more corrosive condensate.

IV. ENVIRONMENTAL ASPECTS OF WATER TREATMENT

A. NATURE OF WASTES

1. Waste products from industrial water treatment processes arise from external and internal water treatment and cleaning operations. Table 18 lists general types of waste chemicals contained in wastewater discharges from the various operations.

B. COMPOSITION OF WASTE DISCHARGES FROM INDUSTRIAL USES

1. Cooling tower wastes vary depending upon type of tower, feedwater quality, and treatment chemicals. Some examples of the chemical analyses of waste discharge, primarily of circulating cooling tower water (similar to cooling tower blowdown) are given in Tables 19 and 20. These analyses show the variation one might expect in the values for a number of water quality parameters. The data shown do not contain any analytical results for specific organic compounds which may have been used in the water treatment. But data on the total organic carbon content of the waste are provided in Table 19, and these data provide an upper limit for the concentration of most organic materials.

2. The data for various cooling tower blowdown wastes indicate that direct discharge of wastes to receiving water is not acceptable in most cases. Of the parameters measured, the ones exceeding limits for most permit discharges are chromium, copper, iron, and phenols. Permit limits for a number of parameters are summarized in Table 21. The excessive oxygen demand substances indicated by the chemical oxygen demand and total organic carbon values also would prohibit direct discharge to most receiving waters. The values for most of the parameters indicate direct discharge to most secondary domestic treatment plants is acceptable. This would have to be established on a case-by-case basis and will depend, to a great extent, upon flow rates.

3. The tests for specific agents that might be used for biological fouling control are not commonly made and were not made in the studies summarized in Tables 19 and 20. These are possibly the only major data lacking to characterize wastes sufficiently for environmental impact in addition to tests for chlorinated hydrocarbons if chlorine is used for biological fouling control.

C. TREATMENT OF WASTES

1. In many cases, discharge of wastes from industrial water treatment to secondary domestic plants is acceptable, providing flow rates are compatible. Exceptions to discharge to sewage treatment plants include wastes from cleaning operations on boilers, solid wastes, and most sludges generated in water treatment.

2. For discharge of wastes to receiving waters, a number of treatment alternatives are available to achieve compliance with regulations. Some of these alternatives are:⁴

a. Fortuitous Treatment - Combining cooling water blowdown with other process effluent streams. Dissolved and dispersed organics reduce chromium to trivalent form, which can be precipitated along with zinc in biological treatment plants.

b. Chromium and Zinc Removal - Three proved techniques are:

- (1) Chemical reduction - reducing chromium with sulfur dioxide and adjusting pH to precipitate chromium and zinc.
- (2) Ion exchange - substituting less toxic anions and cations for chromate and zinc through ion exchange columns.
- (3) Electrochemical - Reducing hexavalent chromium by electrolysis, adjusting pH, and precipitating trivalent chromium and zinc hydroxides.

V. SUMMARY AND CURRENT NAVY PRACTICES

A. SUMMARY

1. The review of aspects of industrial water treatment identified water treatment options, chemicals used, and the nature of the wastes from the various water treatment processes.

B. CURRENT PRACTICES

1. To develop, or determine if there is a need to develop, a system for tracking and providing situation reports on the Navy-wide industrial water treatment status, an accurate picture of the current practices is required. The acquiring of necessary information will be implemented as Phase II of the Industrial Water Treatment Program. The subject areas of prime importance are as follows:

- a. Type of water treatment
- b. Kind and quantities of chemicals and trade name materials used
- c. Volume and characterization of wastes from water treatment operations
- d. Disposition of wastes
- e. Problems associated with treatment and quality of water
- f. Projections related to changes in water treatment procedures

2. The information will be collected through the following:

- a. Existing reports (Environmental Engineering Survey Reports) and logs at NAVFAC Headquarters, Engineering Field Divisions, and activities.
- b. Communication by letter and telephone to appropriate utility engineers
- c. On-site visits to activities to provide the most accurate data.

3. The acquisition of data regarding current practices will be accomplished by the completion of the following tasks:

- a. Review existing reports
- b. Consulting with NAVFAC and EFD's
- c. Activity on-site surveys
- d. Summarize and prepare survey report

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1. Betz Handbook of Industrial Water Conditioning, 7th Edition, Betz, Trevose, PA, 1976.
2. USGS Water Supply Paper No. 1454.
3. ASME Boiler and Pressure Vessel Code Section VI, ASME, 345 E. 47th St., N.Y. 1974
4. Matson, J.V., "Treatment of Cooling Tower Blowdown," Journal of Environmental Engineering, Feb. 1977, 12732.

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Steam - Its Generation and Use, Babcock and Cox, New York, NY, 1972.

The Water Encyclopedia, David Todd, Editor, Water Information Center, Port Washington, NY, 1970.

Water Quality and Treatment, A Handbook of Public Water Supplies, The American Water Works Association, Inc., McGraw-Hill Book Co., New York, NY, 1971.

TABLE 1
WATER QUALITY PARAMETERS

CHEMICAL AND PHYSICAL	NITROGEN AND PHOSPHORUS	ANIONS
Acidity, as CaCO_3	Ammonia (as N)	Bromide
Alkalinity, as CaCO_3	Kjeldahl nitrogen (as N)	Chloride
Biochemical oxygen demand, 5-d (BOD_5)	Nitrate (as N)	Cyanide, total
Chemical oxygen demand (COD)	Nitrite (as N)	Cyanide amenable to chlorination
Chlorine--total residual	Organic nitrogen (as N)	Fluoride
Color, platinum cobalt units or dominant wave length, hue, luminance, purity	Phosphorus (elemental)	Sulfate (as SO_4)
Dissolved oxygen	Orthophosphate (as P)	Sulfide (as S)
Hardness--Total, as CaCO_3	Phosphorus; total (as P)	Sulfite (as SO_3)
Hydrogen ion (pH), pH units		
Specific conductance, microhms per centimeter at 25°C	ORGANICS	BACTERIA
Temperature, degrees C	Benzidine	Coliform (fecal), number per 100 ml.
Turbidity, NTU	Chlorinated organic compounds (except pesticides)	Coliform (fecal) in presence of chlorine, number per 100 ml.
	Oil and grease	Coliform (total), number per 100 ml.
	Organic carbon; total (TOC)	Coliform (total), in presence of chlorine, number per 100 ml.
	Phenols	Fecal Streptococci, number per 100 ml.
	Pesticides	
	Surfactants	

TABLE 1
WATER QUALITY PARAMETERS (CONTINUED)

METALS AND OXIDES	METALS AND OXIDES	RADIOLOGICAL
Aluminum	Mercury	Alpha-Total, pCi per liter
Antimony	Molybdenum	Alpha-Counting error, pCi per liter
Arsenic	Nickel	Beta-Total, pCi per liter
Barium	Osmium	Beta-Counting error, pCi per liter
Beryllium	Palladium	(a) Radium-Total, pCi per liter
Boron	Platinum	(b) ^{226}Ra , pCi per liter
Cadmium	Potassium	
Calcium	Rhodium	
Chromium VI	Ruthenium	
Chromium	Selenium	
Cobalt	Silica	
Copper	Silver	
Gold	Sodium	
Iridium	Thallium	
Iron	Tin	
Lead	Titanium	
Magnesium	Vanadium	
Manganese	Zinc	

TABLE 2

FORMULA WEIGHTS AND EQUIVALENT WEIGHTS OF IONS FOUND IN WATER

(Weights expressed to three significant figures)

Ion	Formula Weight	Equivalent Weight	Ion	Formula Weight	Equivalent Weight
Al	26.98.....	9.00	Fe ³⁺	55.84	18.6
Ba ⁺⁺	137.34.....	68.7	Pb ⁺⁺	207.19	103.6
HCO ₃	61.0	61.0	Li ⁺	6.94	6.94
Br ⁻	79.9	79.9	Mg ⁺⁺	24.31	12.2
Ca ⁺⁺	40.08.....	20.0	Mn ⁺⁺	54.94	27.5
CO ₃ ⁻⁻	60.0	30.0	Mn ⁴⁺	54.94	13.7
Cl ⁻	35.45.....	35.45	NO ₃ ⁻	62.01	62.0
Cr ⁶⁺	52.00.....	8.67	PO ₄ ⁻⁻⁻	94.97	31.7
Cu ⁺⁺	63.6	31.8	K ⁺	39.10	39.1
F ⁻	19.00.....	19.0	Na ⁺	22.99	23.0
H ⁺	1.01.....	1.01	Sr ⁺⁺	87.62	43.8
OH ⁻	17.0	17.0	SO ₄	96.06	48.0
I ⁻	127.90.....	127.9	S ⁻	32.06	16.0
Fe ⁺⁺	55.85.....	27.9	Zn ⁺⁺	65.37	32.7

TABLE 3

CONVERSION FACTORS FOR CONVERTING PARTS PER MILLION
TO MILLIEQUIVALENTS PER MILLION

To convert parts per million to milliequivalents per million*			
Ion		Ion	
	Multiply ppm by:		Multiply ppm by:
Aluminum (Al^{+++})	0.11119	Iron (Fe^{+++})	0.05372
Barium (Ba}^{++}) . . . . .	.01456	Lead (Pb}^{++}) . . . . .	.00965
Bicarbonate (HCO_3^-) . . . . .	.01639	Lithium (Li}^+) . . . . .	.14409
Bromide (Br}^-) . . . . .	.01251	Magnesium (Mg}^{++}) . . . . .	.08224
Calcium (Ca}^{++}) . . . . .	.04990	Manganese (Mn}^{++}) . . . . .	.03640
Carbonate (CO_3^{--}) . . . . .	.03333	Manganese (Mn^{4+}) . . . . .	.07281
Chloride (Cl}^-) . . . . .	.08280	Nitrate (NO_3^-) . . . . .	.01613
Chromium (Cr^{6+}) . . . . .	.11536	Phosphate (PO_4^{--}) . . . . .	.03159
Copper (Cu}^{++}) . . . . .	.03148	Potassium (K}^+) . . . . .	.02558
Fluoride (F}^-) . . . . .	.05263	Sodium (Na}^+) . . . . .	.04350
Hydrogen (H}^+) . . . . .	.99026	Strontium (Sr}^{++}) . . . . .	.02282
Hydroxide (OH}^-) . . . . .	.05880	Sulfate (SO_4^{--}) . . . . .	.02082
Iodide (I}^-) . . . . .	.00788	Sulfide (S}^{--}) . . . . .	.06237
Iron (Fe}^{++}) . . . . .	.03581	Zinc (Zn}^{++}) . . . . .	.03059

* Divide meq/liter by the factor to convert equivalents per million to parts per million.

TABLE 4
COMMONLY USED CONVERSION FACTORS IN WATER TREATMENT

To Convert:	To:	Multiply by:
Grains per Imperial gallon.	Parts per million	14.3
Grains per gallon	Parts per million	17.12
Parts per million	Grains per million. . . . .	.05841
Parts per million	Tons per acre-foot. . . . .	.00136
Ca ⁺⁺	CaCO ₃	2.497
CaCl ₂	CaCO ₃ . . . . .	.9018
Ca(OC1) ₂	CaCO ₃	0.700
HCO ₃ ⁻	CaCO ₃	1.6403
HCO ₃ ⁻	CO ₂	0.9835
Mg.	CaCO ₃	4.117
MgCl ₂	CaCO ₃	1.051
Na ₂ CO ₃	CaCO ₃ . . . . .	.9442
Fe ⁺⁺	CaCO ₃	1.7922
Fe ⁺⁺	H ₂ SO ₄	2.634
Mn ⁺⁺	CaCO ₃	1.8219
NO ₃ ⁻	N . . . . .	.2259
N	NO ₃	4.4266

TABLE 5

SUMMARY OF QUALITY INPUTS TO SURFACE WATERS *

CONTRIBUTING FACTOR	PRINCIPAL QUALITY INPUT TO SURFACE WATERS
Meteorological water	Dissolved gases native to atmosphere Soluble gases from man's industrial activities Particulate matter from industrial stacks dust and radioactive particles Material washed dissolved from surface of earth, e.g.: Organic matter such as leaves, grass, and other vegetation in all stages of biodegradation, Organic extractives from decaying vegetation, Bacteria associated with surface debris (including intestinal organisms), Clay, silt, and other mineral particles, Insecticide and herbicide residues
Domestic use of water	Undecomposed organic matter (polypeptides, starches, fats) from garbage to sewers, partially degraded organic matter such as raw wastes from human bodies; Combination of above two after biodegradation to various degrees by sewage treatment, Bacteria (including pathogens), viruses, worm eggs; Grit from soil washings, eggshells, ground bone, etc. Miscellaneous organic solids, e.g., paper, rags, plastics, and synthetic materials including detergents.
Industrial use of water	Biodegradable organic matter having a wide range of oxygen demand; Inorganic solids, mineral residues; Chemical residues ranging from simple acids and alkalies to those of highly complex molecular structure; Metal ions.
Agricultural use of water	Increased concentration of salts (ions), Fertilizer, insecticide, and herbicide residues; Silt and soil particles; Organic debris, e.g., crop residues; Animal wastes.
Consumptive use (all sources)	Increased concentration of suspended and dissolved solids by loss of water to atmosphere

* Source: McGauhey, Engineering Management of Water Quality, McGraw-Hill, Copyright 1968.

(This list includes the types of things that may come from any contributing factor. Not all are present in each specific instance.)

TABLE 6
SUMMARY OF QUALITY INPUTS TO GROUNDWATERS*

Contributing Factor	Principal Quality Input to Groundwaters
Meteorological Water	<p>Gases, including O₂ and CO₂, N₂, H₂S, and H₂</p> <p>Dissolved minerals, e.g.:</p> <p style="padding-left: 40px;">Bicarbonates and sulfates of Ca and Mg dissolved from earth minerals,</p> <p style="padding-left: 40px;">Nitrates and chlorides of Ca, Mg, Na, and K dissolved from soil and organic decay residues,</p> <p style="padding-left: 40px;">Soluble salts of Fe and Mn and other metals.</p>
Domestic use (principally via septic tank systems and seepage from polluted surface waters)	<p>Detergents</p> <p>Nitrates, sulfates, and other residues of organic decay</p> <p>Salts and ions dissolved in the public water supply</p> <p>Soluble organic compounds.</p>
Industrial use (not much direct disposal to soil)	<p>Soluble salts from seepage of surface waters containing industrial wastes.</p>
Agricultural use	<p>Concentrated salts common to water applied to land</p> <p>Other materials as per meteorological waters.</p>
Land disposal of solid waste (not properly installed)	<p>Hardness-producing leachings from ashes</p> <p>Soluble chemical and gaseous products of organic decay, metals, organic compounds</p>
<p>Variations in the quality of a given body of water result from variations in any of the input factors which stem from conditions listed in this table.</p>	

* Source: McGauhey, Engineering Management of Water Quality, McGraw-Hill, Copyright 1968.

TABLE 7

CONDITIONS THAT MAY CAUSE VARIATIONS IN WATER QUALITY

Condition	Process Causing Variations
Climatic	<p>Runoff from snowmelt - muddy, soft, high bacterial count</p> <p>Runoff during drought - high mineral content, hard, groundwater characteristics.</p> <p>Runoff during floods - less bacteria than snowmelt, may be muddy (depending upon other factors listed below).</p>
Geographic	<p>Steep headwater runoff differs from lower valley areas in ground cover, gradients, transporting power, etc.</p>
Geologic	<p>Clay soils produce mud</p> <p>Organic soils or swamps produce color</p> <p>Cultivated land yields silt, fertilizers, herbicides and insecticides. Fractured or fissured rocks may permit silt, bacteria, etc., to move to groundwater.</p> <p>Mineral content dependent upon geologic formations</p>
Seasons of Year	<p>Fall runoff carries dead vegetation - color, taste organic extractives, bacteria.</p> <p>Dry season yields dissolved salts.</p> <p>Irrigation return water, in growing season only.</p> <p>Cannery wastes.</p> <p>Aquatic organisms.</p> <p>Overtum of lakes and reservoirs.</p> <p>Floods.</p> <p>Dry periods, low flows.</p>
Resource Management Practices	<p>Agricultural soils and other denuded soils are productive of sediments, etc. (See third item under Geologic conditions.)</p> <p>Overgrazed or denuded land subject to erosion.</p> <p>Continuous or batch discharge of industrial wastes alter shock loads.</p> <p>Inplant management of waste streams governs nature of waste.</p>

* Source: McGauhey, Engineering Management of Water Quality, McGraw-Hill, Copyright 1968.

TABLE 8

MAJOR EFFECTS OF CONSTITUENTS IN WATER UPON USABILITY

MAJOR EFFECT OR CAUSE	IMPURITY CONSTITUENT/ PARAMETER	CHEMICAL FORMULA SYMBOL OR DESCRIPTION
Scale/deposits	Turbidity Hardness Sulfate Silica Iron Manganese Suspended Solids Total Solids	suspended matter Ca^{++} and Mg^{++} SO_4^{--} SiO_2 Fe^{++} (ferrous) Fe^{+++} (ferric) Mn^{++} Suspended insoluble matter Soluble and insoluble matter
MAJOR PROBLEM CAUSING EFFECT	CONSTITUENT/PARAMETER	IMPURITY CHEMICAL FORMULA OR DESCRIPTION
Corrosion	Alkalinity Free mineral acid Carbon dioxide Chloride Oxygen Hydrogen sulfide Ammonia	HCO_3^- , CO_3^{--} , OH^- HCl , H_2SO_4 and other acids CO_2 Cl^- O_2 H_2S NH_3
Foaming	Dissolved solids Alkalinity Color	Soluble salts of sodium and potassium. HCO_3^- , CO_3^{--} , OH^- Generally organic materials
Embrittlement of metals	Alkalinity	OH^-
Odor	Hydrogen sulfide Color	H_2S Generally organic material

TABLE 9

RECOMMENDED LIMITING CONCENTRATION RANGES
FOR INDUSTRIAL PROCESS WATERS

CONSTITUENT/ PARAMETER	PROCESS ^a					
	Air Condi- tioning	Baking	Drinking	Food Canning and Freezing	Food Equipment Washing	Food Processing
Turbidity		10	5	1-10	1	1-10
Color Units		10	15	—	5-20	5-10
Taste and Odor Threshold	Low	None-Low	3	None-Low	None	Low
Dissolved Solids			500	850	850	850
Hardness, as CaCO ₃		a	—	h	10	10-250
Alkalinity, as CaCO ₃			—	30-250	—	30-250
pH			—	≥ 7.5	—	—
Chlorides, as Cl			250	—	250	—
Sulfates, as SO ₄			250	—	—	—
Iron, as Fe	0.5	0.2	0.3	0.2	—	0.2
Manganese, Mn	0.5	0.2	0.05	0.2	—	0.2
Iron plus Manganese	0.5	0.2	—	0.2-0.3	0.1	0.2-0.3
Hydrogen Sulfide		0.2	—	1.0	—	—
Fluorides			1.4-2.4	1.0	1.0	1.0
N			Potable			Potable
NaCl				1000-1500		
Nitrate, N				2.8		
Ammonia, N				0.4		
Organics					Very Small	
Other			Potable	Potable		Potable
Organics				No Saprophytic Organisms	Very Small	

^a Concentration units in mg/l unless noted otherwise.

TABLE 10

**LIMITING CONCENTRATION RANGES^a RECOMMENDED FOR BOILER
FEEDWATER QUALITY FOR BOILERS AT VARIOUS PRESSURES**

CONSTITUENT/ PARAMETER	BOILER PRESSURE				
	Low to 250PSI	Intermediate 250-500PSI	High 500-1,500PSI	Very High 1,500-1,500PSI	Super Critical Over 3,000PSI
Total Hardness, as CaCO ₃	0	0	0	0	0
Total Alkalinity as CaCO ₃ , mg/l	-	700-500	500-200	150-100	
Hydroxide, as mg/l CaCO ₃	150-300	130-100	100-50		
Silica, as mg/l SiO ₂	100-133	50-2.1	19-2.1	1.1-0.09	0.02
Dissolved oxygen as mg/l O ₂	0.015	0.007			0.005
Solids, dis- solved mg/l	3,000- 5,000	35,000-5,000	2,500-1,000	750-500	0.05-0.5
Solids, sus- pended, mg/l	300-600	300-150	150-20		
pH (pH units)	9.5	9.7	10.3-10.8	10.3-10.8	9.0-9.6
Oil mg/l	1.0	0.1	--	--	
Iron, as mg/l Fe	--	--	--	--	0.1
Copper as mg/l Fe					0.1
Phosphate, as mg/l PO ₄	40-80	50-20	20-40		
Organic dis- persant, mg/l	50-75				

^a These values are minimum, all others are maximum

^b From Water Quality and Treatment, American Water Works Association, 3rd Ed., McGraw-Hill Book Co., New York, 1971.

TABLE 11
LIMITS ON CIRCULATING COOLING WATER QUALITY

PROBLEM AREAS	WATER QUALITY CONTROL GENERALIZATIONS
<u>Corrosion</u>	
Minimum Corrosion	200 to 500 ppm Sodium Chromate with minimum pH of 7.
Lower Chemical Costs	20 to 50 ppm sodium chromate plus equal amounts of cohibitor like polyphosphate and pH control between narrow limits of 6.2 to 6.8.
Galvanic Corrosion	By limiting total dissolved solids to not over 2,000 ppm.
<u>Scale Control</u>	
Index Control	Positive Langelier Index 0.5 to 1.0 with some variation depending upon the maximum temperature in the system.
Alkalinity Control	If sulfuric acid is fed for calcium carbonate scale control, makeup alkalinity is usually held to 15 to 25 ppm, and circulating water alkalinity in the 50 to 100 ppm range.
Delignification of Wood Structures	pH held to maximum of 7 Chlorine for slime and algae control held to 1 ppm.

TABLE 12

**SUMMARY OF CONVENTIONAL WATER TREATMENT PROCESSES
FOR CONTROL OF MUNICIPAL AND INDUSTRIAL WATER QUALITY***

TYPE OF TREATMENT PROCESS	PRINCIPAL CHANGE IN QUALITY FACTORS FOR MUNICIPAL SUPPLY
<u>Gravity Separation</u>	
Plain Sedimentation	Removes larger and heavier suspended solids.
Sedimentation after Chemical Coagulation	Unspecified reduction in BOD, suspended solids and bacteria.
Chemical Coagulation Plus Sedimentation	Reduces suspended solids, turbidity, and color. Hardness to 75mg/liter. Excess lime to 30-50 mg/liter. Not process to less than 10 mg/liter as CaCO ₃ . Reduces iron to 0.1mg/liter. Removes CO ₂ which requires restabilization. 80-100% reduction in bacteria by excess lime.
<u>Filtration</u>	
Slow Sand (gravity)	99% reduction in bacteria. 95-100% reduction in turbidity. 30% reduction in color. Reduction in tastes and odor. 60% reduction in iron.
Rapid Sand (gravity)	95% reduction in bacteria. 90% reduction in turbidity.
Rapid Sand Plus Chemical Coagulation (gravity)	90-99% reduction in bacteria. 99+% reduction in turbidity. Color to less than 5 color units. Alkali increased 7.7 mg/liter/gr. alum. Iron reduced slightly. Odor and taste removed partially.
Rapid Sand Plus Chemical Coagulation, Chlorination, and Activated Carbon	99+% reduction in bacteria. 100% reduction in turbidity. Color reduced to near zero. Fe and Mn reduced. Odor and taste reduced significantly.

* Source: McGauhey Engineering Management of Water Quality, McGraw-Hill, 1968.

TABLE 12 (Cont'd)

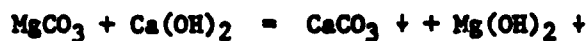
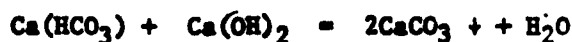
**SUMMARY OF CONVENTIONAL WATER TREATMENT PROCESSES
FOR CONTROL OF MUNICIPAL AND INDUSTRIAL WATER QUALITY**

TYPE OF TREATMENT PROCESS	PRINCIPAL CHANGE IN QUALITY FACTORS FOR MUNICIPAL SUPPLY
<u>Filtration (Continued)</u>	
Rapid Sand (pressure) (precoat with chemical floc)	Similar to rapid sand filter but more variable in performance.
Diatomaceous Earth (pressure and vacuum)	40-90% reduction in suspended solids. Color reduced 50%.
Contact Filters	Fe reduced 88%.
Carbon Filters	Organic chemicals absorbed. Tastes and odors removed. Gases absorbed.
<u>Aeration</u>	
Spray or Cascade	Gases producing taste and odor are removed. CO ₂ removed to normal surface water levels. H ₂ S removed partially. Oxidation and removal of soluble iron.
<u>Demineralization</u>	
Ion Exchange (natural or synthetic zeolite)	Ca and Mg decreased with corresponding increase in Na.
Ion Exchange (green- sand or styrene base gels)	Fe removal to 90-99%+ some Mn removal.
Ion Exchange (organic cation exchangers)	All cations (Na, K, Mg, Fe, Ca, Mn) removed.
Ion Exchange (anion exchangers)	SO ₄ ⁻ , Cl ⁻ , NO ₃ ⁻ , etc. removed.
Ion Exchange (fluoride exchangers)	F ⁻ removal up to 99% possible.
Reverse Osmosis	TDS, ABS, and COD reduced by up to 97-98%.

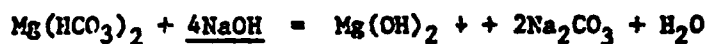
TABLE 13

CHEMICAL REACTIONS RELATED TO WATER TREATMENT

a. Lime-Soda Process



b. Caustic Soda Treatment



c. Hot Lime-Soda Softening

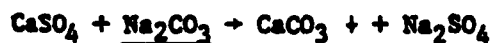
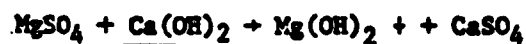
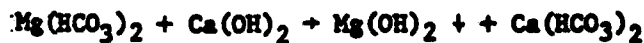
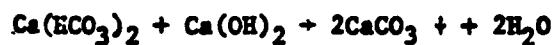
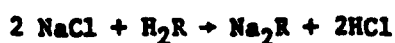
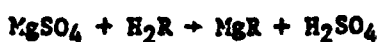
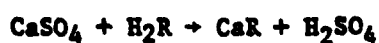
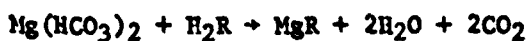
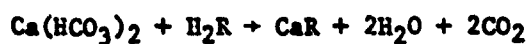
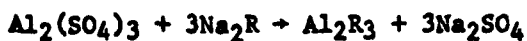
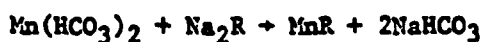
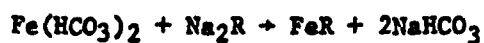
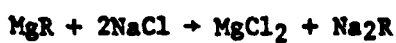
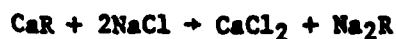
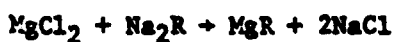
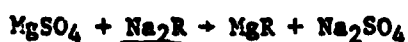
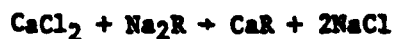
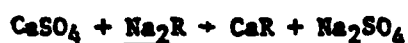
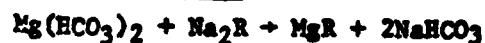
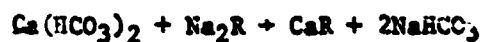


TABLE 13 (Cont'd)

CHEMICAL REACTIONS RELATED TO WATER TREATMENT

d. Ion-Exchange Softening



R = anionic component of the ion exchangers such as greensand, processed greensand, synthetic siliceous zeolite, sulfonated coal, phenolic resin, and polystyrene resin. Frequently, R is represented by the symbols ZSO_3H where Z represents a complex resin material and $-\text{SO}_3\text{H}$ is a sulfonic acid functional group attached chemically to the resin. The sulfonic acid groups make the resins strongly acidic cation exchangers. Strongly basic anion exchange resins derive their functionality from the quaternary ammonium sites, e.g.,

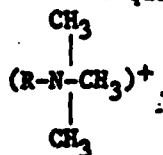
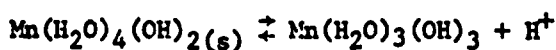
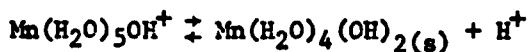
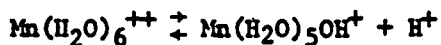
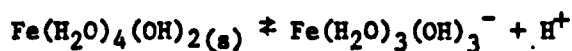
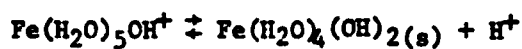
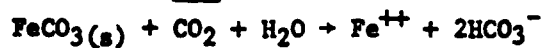
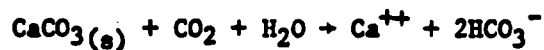


TABLE 13 (Cont'd)

CHEMICAL REACTIONS RELATED TO WATER TREATMENT

e. Iron and Manganese Removal



Polymerization reactions--See reactions under coagulations and flocculation.

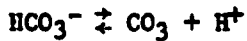
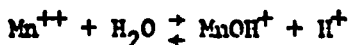
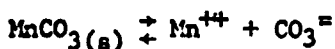
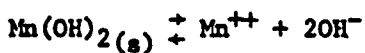
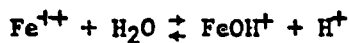
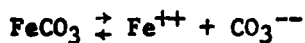
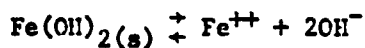


TABLE 13 (Cont'd)

CHEMICAL REACTIONS RELATED TO WATER TREATMENT

f. Coagulation/Flocculation

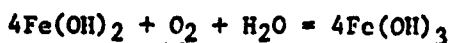
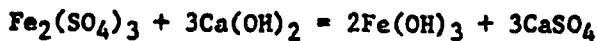
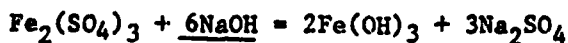
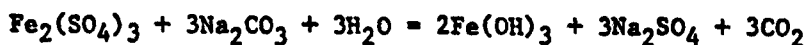
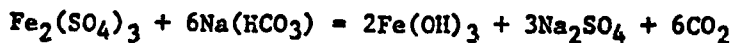
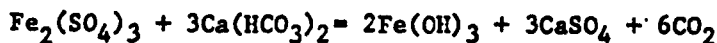
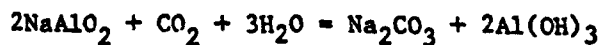
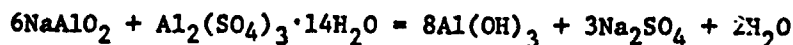
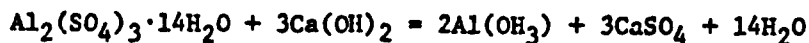
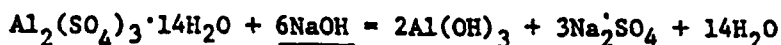
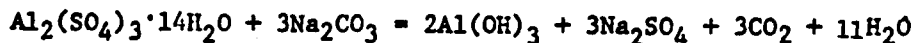
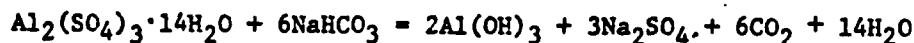
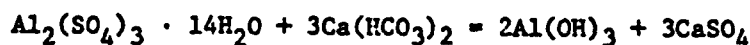
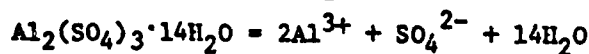
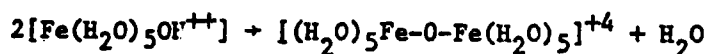
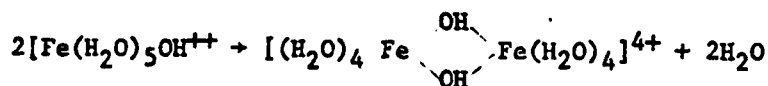
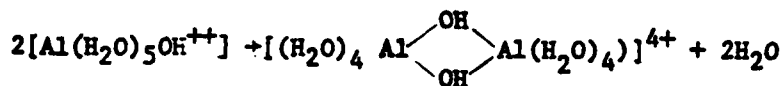
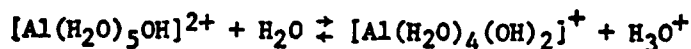
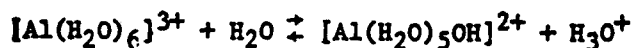
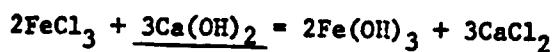
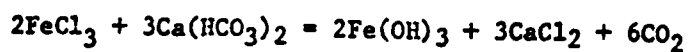
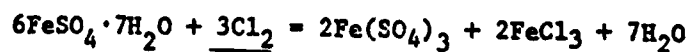
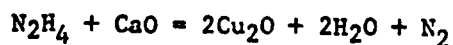
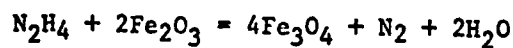
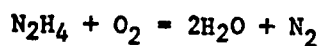
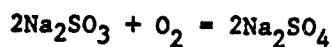
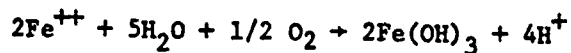
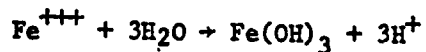
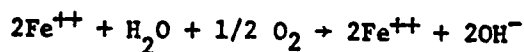
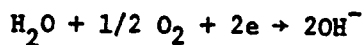
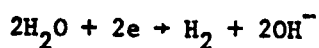
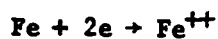


TABLE 13 (Cont'd)

CHEMICAL REACTIONS RELATED TO WATER TREATMENT



g. Corrosion



h. Chlorination

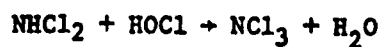
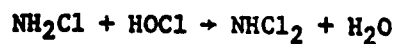
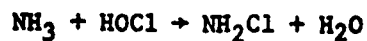
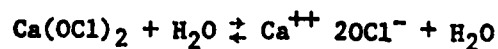
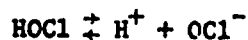
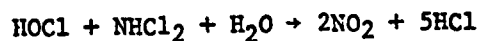
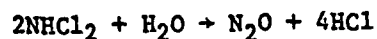
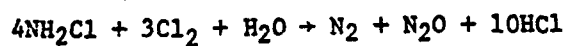
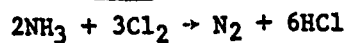
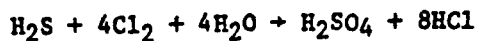


TABLE 13 (Cont'd)

CHEMICAL REACTIONS RELATED TO WATER TREATMENT



Internal Treatment - Scale Prevention

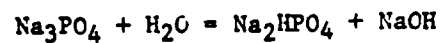
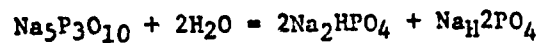
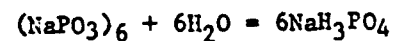
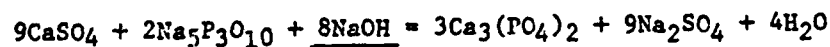
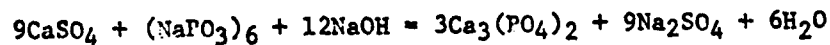
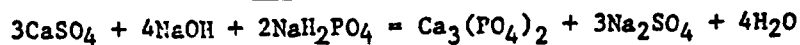
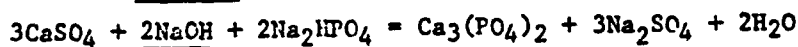
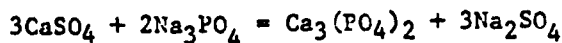


TABLE 14
INORGANIC CHEMICALS USED FOR WATER TREATMENT

CHEMICAL NAME AND FORMULA	COMMON OR TRADE NAME	CHEMICAL NAME AND FORMULA	COMMON OR TRADE NAME
Aluminum sulfate $\text{Al}_2(\text{SO}_4)_3$	Alum, filter alum sulfate of alumina	Hydrogen fluoride, HF	Hydrofluoric acid
Ammonium aluminum sulfate, $\text{NH}_4\text{Al}(\text{SO}_4)_2$	Ammonia alum, crys- tal alum	Sodium fluoride NaF	fluoride
Bentonite	Colloidal clay, volclay, wilkinite	Sodium silico fluoride, Na_2SiF_6	Sodium silico- fluoride
Ferric chloride (a) FeCl_3 (35-45% solution) (b) $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ (c) FeCl_3	"Ferrichlor," chloride of iron Crystal ferric chloride Anhydrous ferric chloride	Disodium Phosphate $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ Sodium hexameta- phosphate, (NaPO_3) ₆	Basic sodium phosphate, DSP, secondary sodium phosphate "Calgon," glassy phos- phate, vitreous phosphate
Ferric sulfate $\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$	"Ferrifloc," Ferrisul	Sodium hydroxide, NaOH	Caustic soda, soda, lye
Ferrous sulfate $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	Copper as, green vitriol	Sulfuric acid H_2SO_4	Oil of vitriol, vitriol
Potassium aluminum sulfate, K_2SO_4 $\text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$	Potash alum	Tetrasodium pyro- phosphate, $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$	Alkaline sodium pyro- phosphate, TSPP
Sodium aluminate, $\text{Na}_2\text{OAl}_2\text{O}_3$	Soda alum	Trisodium phosphate $\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$	Normal sodium phos- phate, tertiary sodium phosphate, TSP
Sodium silicate Na_2OSiO_2	Water glass	Calcium hydroxide, $\text{Ca}(\text{OH})_2$	Hydrated lime, slaked lime
Ammonium silico fluoride, (NH_4) SiF_6	Ammonium fluor- silicate	Calcium oxide, CaO	Burnt lime, chemical lime, quicklime, un- slaked lime
Calcium fluoride, CaF_2	Fluorspar	Sodium carbonate, Na_2CO_3	Soda ash
Hydro-fluosilicic acid H_2SiF_6	Fluosilicic acid	Sodium chloride NaCl	Common salt Salt

TABLE 14 (Cont'd)

INORGANIC CHEMICALS USED FOR WATER TREATMENT

CHEMICAL NAME AND FORMULA	COMMON OR TRADE NAME	CHEMICAL NAME AND FORMULA	COMMON OR TRADE NAME
Activated carbon C	"Aqua nuchar," "Hydroadarco," "Norite"	Calcium hypochlorite, $\text{CaOCl}_2 \cdot 4\text{H}_2\text{O}$	"HTH," Perchloron "Pitchlor"
Chlorine Cl_2	Chlorine gas, liquid chlorine	Chlorinated lime, $\text{CaO} \cdot 2\text{CaOCl}_2 \cdot 3\text{H}_2\text{O}$	Bleaching powder Chloride of lime
Chlorine dioxide, ClO_2	Chlorine dioxide	Chlorine, Cl_2	Chlorine gas Liquid chlorine
Copper sulfate $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	Blue vitriol, blue stone	Chlorine dioxide, ClO_2	Chlorine dioxide
Ozone O_3	Ozone	Ozone, O_3	Ozone
Potassium permanganate, KMnO_4	Purple salt	Pyrosodium sulfite	Sodium metabi- sulfite
Ammonium aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3(\text{NH}_4)\text{SO}_4 \cdot 24\text{H}_2\text{O}$	Ammonia alum, crystal alum	Sodium Chlorite, NaClO_2	Technical sodium chlorite
Ammonium sulfate $(\text{NH}_4)_2\text{SO}_4$	Sulfate of ammonia	Sodium hypochlorite, NaOCl	Sodium hypochlorite
Anhydrous ammonia, NH_3	Ammonia	Sodium sulfite, Na_2SO_3	Sulfite
Aqua ammonia NH_4OH	Ammonia water, Ammonium hydrate, Ammonium hydroxide	Sulfur dioxide, SO_2	Sulfurous acid anhydride

TABLE 15

CHEMICALS USED FOR HEATING BOILER TREATMENT

<u>Inorganic</u>	<u>Formula</u>
Sodium hydroxide (caustic soda)	NaOH
Trisodium phosphate (TSP)	Na ₃ PO ₄
Sodium acid phosphate	NaH ₂ PO ₄
Sodium tripolyphosphate	Na ₅ P ₃ O ₁₀
Sodium borate	Na ₂ B ₄ O ₇
Sodium chromate	Na ₂ CrO ₄
Sodium sulphite	Na ₂ SO ₃
Sodium nitrate	NaNO ₃
Sodium nitrite	NaNO ₂
<u>Organic</u>	
Natural organics	
Sodium alginate and other seaweed derivatives	
Quebracho tannin	
Lignin sulfonate	
Starch	
Synthetic	
EDTA (Ethylene diamine Tetraacetic acid)	
NTA (nitrilo triacetic acid)	

OTHER CHEMICALS USED IN BOILER OPERATION

Antifoam agents

Polymerized esters
alcohols
amides

Corrosion control

Neutralizing amines

Morpholine	C ₄ H ₉
Diethyl aminoethanol	(C ₂ H ₅) ₂ NCH ₂ CH ₂ OH
Dimethylpropylamine	(CH ₃) ₂ NCH ₂ CH ₂ CH ₃
Cyclohexylamine	C ₆ H ₁₃ N
Ammonia	NH ₃

Filming amines

Octadecylamine	CH ₃ (CH ₂) ₁₇ NH ₂
Octadecylamine acetate	CH ₃ (CH ₂) ₁₇ NH ₂ CH ₃ CO ₂ H

Other

Hydrazine	N ₂ H ₂
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TABLE 16

CHEMICALS USED IN CLEANING STEAM GENERATOR SYSTEMS

Alkaline Cleaning

Trisodium phosphate
Surfactant
Sodium hydroxide
Sodium silicates
Sodium nitrate
Sodium sulfite
Commercial alkaline cleaning products

Acid Cleaning

Hydrochloric acid
Sodium carbonate

Chelating Agents

Sodium and ammonium salts of EDTA (6% solutions)

Removal of Copper Deposits

Sodium chlorate
Ammonia
Ammonium sulfate
Ammonium nitrate
Potassium bromate
Ammonium persulfate
Ammonium bromate
Ammoniated citric acid
Ammoniated salts of EDTA
Formic acid
Hydroxy acetic acid
Diethylthiourea

TABLE 17

CHEMICALS USED FOR MICROBIOLOGICAL AND WOOD DETERIORATION CONTROL

Microbiological Control Chemicals

Chlorine
Chlorine dioxide
Phenolics
Chlorinated phenolics
Quaternary ammonium compounds
Copper salts
Mercurial compounds
Various proprietary biocides possibly containing:
• Methylene bithiocyanate
• Bix (tributyltin) - oxide
• dodecylguanidine hydrochloride
• organic bromine compounds

Wood Deterioration Control Chemicals

Creosote
Ammoniacal copper arsenite
Acid copper chromate
Copper naphthenate
Chromated copper arsenate
Pentachlorophenol
Fluoride chromate arsenate phenol mixture
Chlorinated paraffin

TABLE 18

TYPICAL WASTE MATERIALS FROM WATER TREATMENT PROCESSES

TREATMENT PROCESS	MOST ABUNDANT CHEMICALS BEING WASTED AS SOLIDS WASTE OR IN SLURRY FORM
Lime-soda process	CaCO_3 , Mg(OH)_2 , sulfates, suspended solids.
Caustic soda treatment	CaCO_3 , Mg(OH)_2 , suspended solids.
Hot lime-soda	CaCO_3 , Mg(OH)_2 , $\text{Ca}_3(\text{PO}_4)_2$
Ion-exchange	CaCl_2 , MgCl_2 , HCl , FeCl_3 , Al(OH)_3 , Mn(OH)_2 , SiO_2
Coagulation/Flocculation	Al(OH)_3 , Fe(OH)_3 , Mn(OH)_2 , CaCl_2
Chlorination	Chloramines Chlorinated organics
Boiler blowdown	Phosphates, carbonates, tannin, lignin sulfonate, polymerized esters, chromates, antifoam agents (alcohols, amides), corrosion control compounds (morpholine, diethyl amminoethanol, dimethylpropylamine cyclohexylamine, hydrazine, EDTA (ethylenediamine-tetracetic acid) zinc salts), corrosion products (iron, copper, and other metal salts), inorganic compounds in sludge.
Cooling tower blowdown	Corrosion and fouling control (hexavalent chromium, zinc salts, polyphosphates, phosphonates), biological fouling control agents (chlorinated phenols, chlorine, algicides, corrosion products (organic components extracted from wood products)

TABLE 19

COOLING TOWER WATER COMPOSITION IN DIFFERENT SYSTEMS^a

PARAMETER	COOLING TOWER NO.			
	1	2	3	4
Alkalinity, MO. mg/l as CaCO ₃	160	207	450	26
Alkalinity, P, mg/l as CaCO ₃	7	8	0	0
Oxygen demand, chemical, mg/l as O ₂	109	18	354	112
Chloride, mg/l	14	35	670	64
Chromates, Hex, mg/l Cr	<0.01	<0.01	625	20
Total hardness, mg/l as CaCO ₃	302	224	940	970
Calcium hardness, mg/l as CaCO ₃	257	151	3433	800
Nitrate, mg/l as N	0.22	0.36	0.80	1.1
Organic nitrogen, mg/l as N	2.0	1.1	2.0	1.4
pH	8.3	8.5	7.0	6.1
Phenols, mg/l as phenol	0.080	0.080	0.39	0.17
O-phosphate, mg/l as P	0.35	0.14	2.45	6.5
Polyphosphate, mg/l as P	0.05	0.05	0.91	0.49
Total solids, mg/l	1119	365	8435	3800
Chromium, mg/l as Cr	<0.01	<0.03	700	25
Copper, mg/l as Cu	0.8	<0.1	<0.1	0.2
Lead, mg/l as pb	<0.1	<0.1	<0.1	<0.1
Zinc, mg/l as Zn	<0.1	0.1	0.2	4.2
Mercury, mg/l as Hg	0.001	0.0005	0.0004	0.0007
Iron, mg/l as Fe	<0.05	<0.05	<0.05	0.55

Evaluation of Cooling Tower Water System Treatment, E. Sevi, P.E., SOUTHNAVFACENGCON, March 1974.

TABLE 20

CHEMICAL ANALYSIS OF BLOWDOWN WATER^a

WATER QUALITY PARAMETER	COOLING TOWER I		COOLING TOWER I-A		COOLING TOWER II
	MAKEUP	BLOWDOWN	MAKEUP	BLOWDOWN	BLOWDOWN
Total organic carbon, mg/l	22.4	87.1	--	5	--
Kjeldahl nitrogen, mg/l	0.38	2.4	<0.01	0.4	--
Ammonia nitrogen, mg/l	0.007	0.067	<0.001	0.002	0.0065
Nitrite nitrogen, mg/l	0	0.025	0.003	0.052	0.006
Nitrate nitrogen, mg/l	0.52	6.0	0.031	0.760	0.113
Ortho phosphorus, as PO ₄ , mg/l	0.011	1.4	--	--	--
Chromium, µg/l	<20	<20	10	26,000	7600
Copper, µg/l	20	200	5	29	11
Iron, µg/l	440	6000	39	39	240
Manganese, µg/l	10	220	4	6	1.2
Lead, µg/l	--	--	<10	14	240
Zinc, µg/l	--	--	68	40	1200

^a Source: R. M. Manabe, EPA-660/2-73-039, Table 5.

TABLE 21

NUMERIC LIMITS FOR NPDES PERMIT PARAMETERS

PARAMETER FOR WATER QUALITY	NUMBER OF DISCHARGE POINTS	RANGE OF NUMBER LIMITS ^a MAXIMUM
Aluminum	2	4.4
Ammonia, N	8	1-15
Arsenic	11	0.02
Barium	1	2.0
Benzene	1	10
Beryllium	2	1.5
Bioassay	9	50-90%
Biochemical oxygen demand	221	3-67.6
Boron	1	0.2 Kg/day
Cadmium	19	0.01-3.6
Chemical oxygen demand	4	125
Chloride	2	30-300
Chlorinated hydrocarbons	4	0.004
Chlorine residual	38	0.2-2.0 (min)
	87	0.2-2.5 (max)
Chromium	29	0.01-5.0
Color	2	4-40 color units
Copper	23	0.02-5.0
Cyanide	15	0.01-1.8
Dissolved oxygen	52	3.0-5.0 (min)
Fecal coliform	114	70-4000 MPN/100 ml
Flow, total	19	2000 gpd - 4 MGD
Fluoride	1	0.4
HMX	2	0.1
Iron	13	0.3-4.3
Lead	17	0.05-2.0
Mercury	5	0.002-0.06
Nickel	6	0.5-1.0
MBAS	10	0.1-2.0
Nitrogen/phosphorous ratio	1	10
Oil and grease	214	5-20
pH (pH units)	144	6.0-6.7 (min)
pH (pH units)	140	8.0-9.0 (max)
phenols	21	0.1-2.0
Salinity	4	20-35
Secchi disc	3	2-12 meters (min)

TABLE 21 (Cont'd)

NUMERIC LIMITS FOR NPDES PERMIT PARAMETERS

PARAMETER FOR WATER QUALITY	NUMBER OF DISCHARGE POINTS	RANGE OF NUMBER LIMITS ^a MAXIMUM VALUES
Selenium	2	0.01
Settleable solids	51	0.1-0.2 ML/L/HR
Silver	8	0.01-0.05
Sulfides	1	0.1
Sulfites	1	12
Thallium	1	1.0
Tin	4	5.0
Titanium	1	0.4
Total Coliform	2	2.2-2000 MFC/100ML
Total Coliform	7	23-2000 MPN/100ML
Nitrogen, Total Kjeldahl	3	5-14
Total phosphorous	12	0.1-15
Total suspended solids	363	15-60

^a Values in milligrams per liter unless indicated otherwise. Values from all types of discharges and receiving bodies of water. Based on limits set for 1974 - 1980 period.

